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EIC Detector R&D Progress Report

Project ID: eRD15
Project Name : R&D for a Compton Electron Detector
Period Reported: from 07/22/2016 to 01/04/2017
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Abstract

Precision polarimetry is an important component for the EIC. It aims at reaching 1% level precision. Compton Polarimetry is commonly use for electron polarimetry. It allows a non invasive measurement of the electron polarization. Accuracies up to 0.52% were achieved using the Compton Electron detection. Sub-percent precision is foreseeable for EIC though the significantly higher current and space constraints require an extensive study. This proposal is looking at the option of a semi-conductor detector in a Roman Pot chamber to detect the Compton electrons.

EIC Detector R&D Progress Report

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June 19, 2017

1 Progress Report Section

1.1 Past

1.1.1 What was planned for this period?

Here is the list of task that were approved by the committee for fiscal year 2017.

- implement simulation on the farm and run with the full detector setup to determine background in the detector from the interaction point
- complete beamline pipe in simulation to look a background contribution from the pipe
- implement beam halo in simulation
- implement polarization analysis and study the systematics
- complete the wakefield simulation to have a first estimate of the power deposit in the detector to determine if Roman Pot design is doable for the electron side
- study of synchrotron radiation effect in the detector
- reduce background and protect detector through shielding
- study of effect of shielding on measurement
- (not funded) show a detector can reach less than 100 ns pulse width making it compatible with eRHIC beam structure

Also from last EIC user meeting, a parity violation experiment was presented which would benefit of accuracy better than 0.5 % on electron polarimetry making this study all the more relevant to determine the ultimate accuracy that can be achieved for a parity violation program.

1.1.2 What was achieved ?

All goals for the 2016-2017 period were achieved.

1.1.3 Report

Simulation and software (Joshua Hoskins)

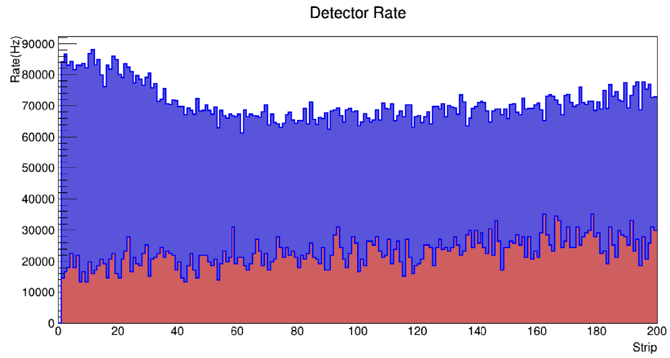

Figure 1: *Simulated rates for apertures of 1 cm (blue) and 2 cm (red). Rates could be further reduced by widening the aperture more.*

Simulations The focus of the simulations efforts has been determination of signal-to-noise by providing an estimate of the backgrounds from halo, scattering from the upstream interaction point, and Bremsstrahlung. As mentioned in the mid-term report the chicane geometry, electron detector, and apertures have been implemented and more recent focus has been on fine tuning their design parameters; this is particularly important for the electron detector position as discussed later. In tandem with the adjustments to the simulation geometry the Compton generator was tweaked, the halo generator was updated to better represent realistic beam conditions, and the polarimetry fitting code was completely redone to work with the current Compton chicane geometry. I discuss the changes and estimates of the total signal-to-noise below.

Halo Generator In the previous update I reported that I had completed the development of a halo generator to investigate backgrounds generated due to halo interaction with mirror apertures associated with a Fabry-Perot cavity in the Compton chicane. In conjunction with this study I have also looked at the effect of the halo interacting directly with the electron detector; as the beam evolves moving through the chicane there could be direct scattering of the halo with the electron detector.

The halo function was modeled using a double Gaussian distribution as described in the PEPII report given by,

$$\frac{dN}{dxdy} = e^{-\frac{x^2}{2\sigma_x^2}-\frac{y^2}{2\sigma_y^2}} + Ae^{-\frac{x^2}{2(S_x\sigma_x)^2}-\frac{y^2}{2(S_y\sigma_y)^2}}. \tag{1}$$

Where $\sigma_{x,y}$ is the beam size, A = 7.2 x 10^{-5} is an estimate of the relative amplitude of the halo, and $S_{x,y}$ is a multiplier used to describe the beam halo in terms of the beam sigma. The vertex of events used in the halo simulation were defined as,

$$X_v = X_{beam} + X_{halo} \tag{2}$$

where X_{beam} is sampled from a 2D Gaussian with $\sigma_{x,y}$ defined by the beam size and X_{halo} was sampled from the halo distribution.

The halo interaction with the apertures was done using estimated beam sizes of $\sigma_{x,y} = \{356`\mu m, 115`\mu m\}$ and a halo multiples of $S_{x,y}$ = 10. The apertures were slotted in the direction of the beam bend with dimensions of 4 cm x 1 cm. Since the slotting is in the direction of the beam bend most of the interaction comes from the width of the aperture. The rates for two width values are show below in Fig. 1. The rates show above have been estimated for a beam current of 1A and have been weighted to account for the fact that we don't sample the full distribution. Given that the core of the halo distribution does not interact at all the distribution is only sampled from the aperture edge to the beam pipe. The weighting associated with this is given by,

$$w_{tail} = erf(\frac{y_{upper}}{\sqrt{2}\sigma_y S_y}) - erf(\frac{y_{lower}}{\sqrt{2}\sigma_y S_y}). \tag{3}$$

We also had to account for the fraction of the beam that was actually halo. This was done by

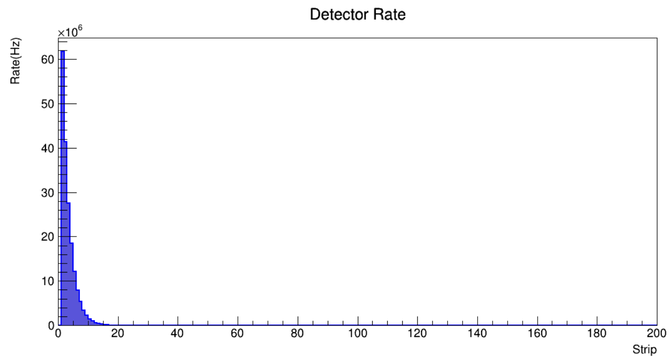

Figure 2: *Background rate due to scattering of the halo tail from 5-7σ from the electron detector edge.*

calculating the halo fraction defined by,

$$w_{halo} = \frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} Ae^{-\frac{x^2}{2(S_x\sigma_x)^2}-\frac{y^2}{2(S_y\sigma_y)^2}}dxdy}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} e^{-\frac{x^2}{2\sigma_x^2}-\frac{y^2}{2\sigma_y^2}}dxdy}. \tag{4}$$

While the rates are high, even for the larger aperture, there is potential to further widen the opening which would lead to even more dramatic rate reductions. For this reason we feel the rates could easily be brought down into the Hz range.

In order to study potential scattering of the halo directly from the electron detector current estimates of the beam optics in the Compton chicane were used to determine the beam profile at the detector. These values were used as the starting $\sigma_{x,y}$ input to the simulation. The electron detector was also moved so that the bottom edge just captured the zero-crossing so that we could distance the detector from the halo as much as possible.

A background rate of this magnitude would mean serious work needs to be put into the beam tune, reduction of halo, and potential shielding, however it is important to consider for a moment the model we are using. While the general form of the halo distribution function is well defined, the assumed amplitude of the halo contribution, A, and the halo multipliers which define the size of the tails are somewhat arbitrary. From the PEPII paper the values seemed don't seem to have been chosen based on any sort of experimental results and therefore could be set to anything. If the multiplier in the direction of the beam bend, which accounts for the majority of the background at the detector, is set to $\sigma_x = 3.3$ as in the original paper (this was made larger in our case because it is expected the halo should be larger in the direction of the beam bend) the background rate drops to the kHz level. The point being that the results of the halo study are highly model dependent and we do not currently have a model with well defined estimates of amplitude and halo magnitude. Given the potential backgrounds this would seem to be an area of interest to devote some study to moving forward.

Compton Generator The Compton event generator and accompanying analysis software were developed as of the last update and the software has now been refined further. Using the generator we have preformed GEANT4 simulations to characterize the electron detector rate and signal-to-noise ratio. Simulations were done for a single pass, CW laser with 10 W of power. The beam energy was taken to be 5 GeV at 1 A current and the beamline vacuum was set to be 10^{-9}. Compton rates are cross-section and luminosity weighted. Signal-to-noise results for both the electron detector and photon detector using GEANT3 are shown in Figure 3 and results for the electron detector using GEANT4 are shown in Figure 4.

Results from both GEANT3 and GEANT4 are consistent in the predictions of the electron detector rates and signal-to-noise suggests, not taking into account additional backgrounds from the upstream interaction region, that a 10 W single pass laser could be a valid choice. The measured asymmetry in the detector for 100% polarization was computed in Figure. 5 and is consistent with theoretical predictions.

An estimate of the radiation dose was computed using simulation in Figure. 6. The plot shows that the majority of the dose is due to Compton scattering with fairly low rates during laser off periods. More work is to be done in determining the time needed to make a sufficient measurement of the polarization

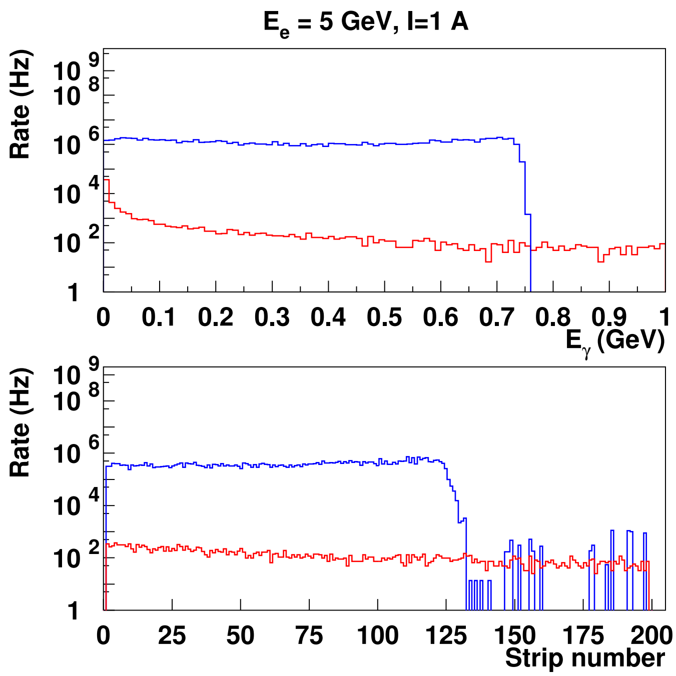

Figure 3: *Simulated rates in the photon detector (top) and electron detector (bottom) for Compton backscattering (blue curve) and Bremsstrahlung (red curve). The beamline vacuum is taken to be 10^{-9} with a beam energy/current of 5 GeV/1 A. The electron detector spectrum is plotted vs. strip number in this case strip 25 corresponds to the zero-crossing of the asymmetry (about 2 cm from the beam for our layout).*

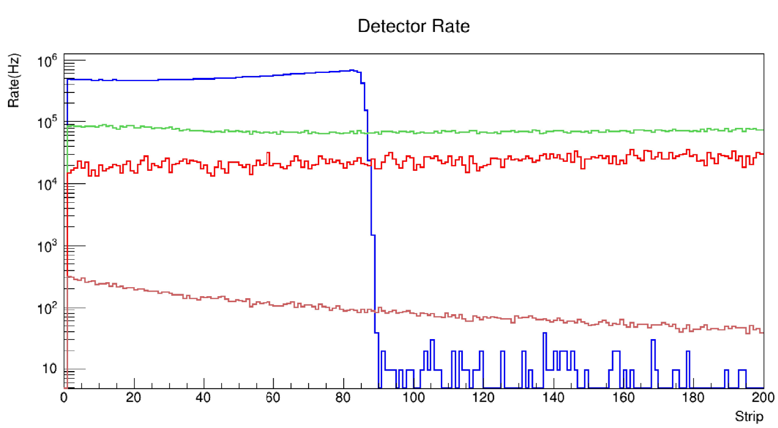

Figure 4: *Composite rate in electron detector due to both background and Compton scattering. The background due to Bremsstrahlung is shown in orange, Compton in blue, and halo due scattering from the aperture in green (1 cm) and red (2 cm). No included is the halo rate from interaction with the electron detector and backgrounds from the upstream IP which are negligible.*

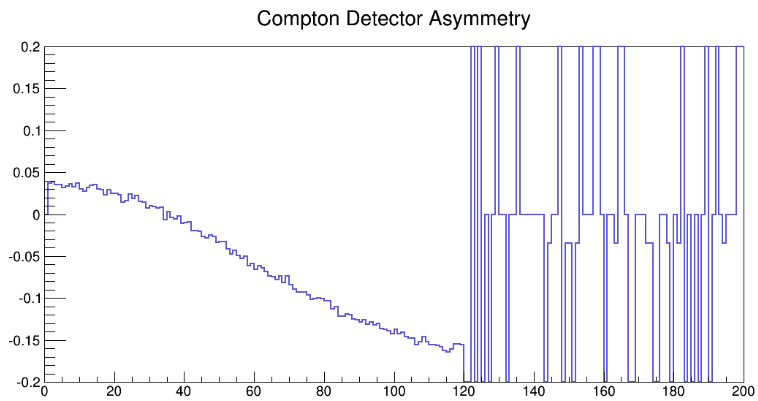

Figure 5: *Simulated asymmetry on the seen in the electron detector for 100% polarization.*

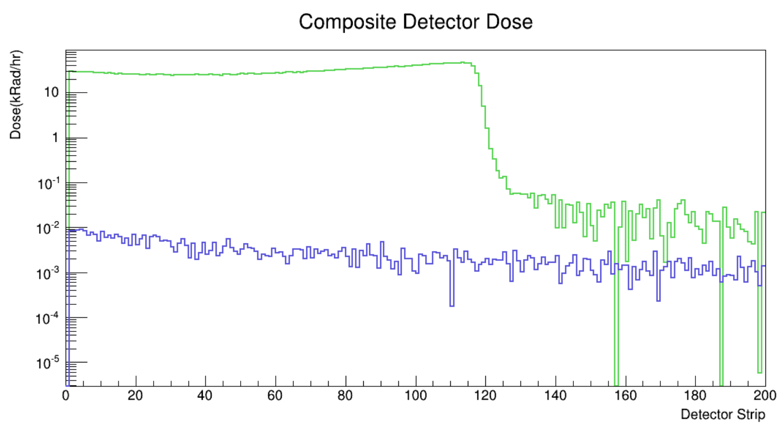

Figure 6: *Radiation dose (kRad/hr) on electron detector due to background(blue) and Compton scattering(green).*

and determine the best choice of detector, however dose rate per hour per strip the simulation give a radiation hard detector such as diamond is a top candidate.

Upstream Interaction Point In addition to the halo study we looked at the potential backgrounds in the Compton chicane from electron-proton scattering at the upstream interaction point. Events were generated using Pythia code from Kijun Park of Jefferson Laboratory. Simulated electrons were at an energy of 5 GeV and simulated protons were at an energy of 100 GeV. The background contribution in the electron detector can be seen in Fig. 7 and is negligible.

Compton Polarization Fitting The polarization extraction code has been updated to work with the current chicane geometry. Previously we had been unable to use the code due to difference in the design of the JLEIC chicane and the Hall C chicane which the code was written for. The benefit of the polarization extraction code is that it allows us to look at different systematics and that we understand our system. In the Fig.8 the fitted Compton asymmetry including fit residuals is shown. The asymmetry and polarization extraction was done with and without a shielding window as an exercise to investigate and smearing that might occur and how that effects the out ability to extract the polarization. The stainless steel window was added 5 mm upstream of the electron detector and, to enhance the effect, was $250\mu m$ thick. The fit results are shown in Table 1 below.

Preliminary results show that percent level accuracy can be reached with the roman pot window. Further studies will be done to evaluate if 0.4% could be reached without having the detector in vacuum.

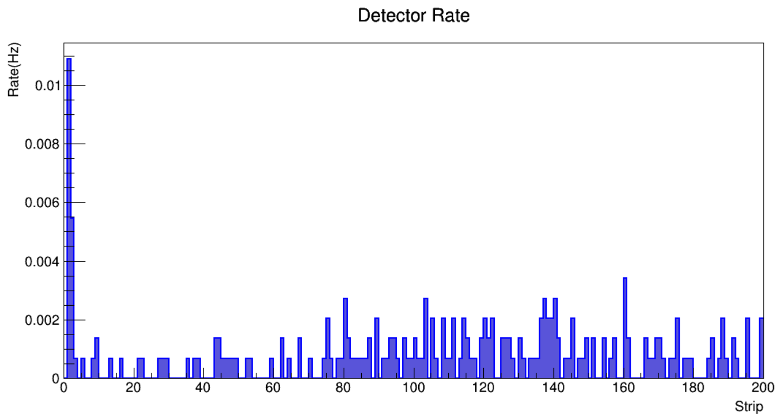

Figure 7: *Background due to electron-proton scattering of 5 GeV electrons and 100 GeV protons at the upstream interaction point. The measured rate in the detector is for 1A and is cross-section and luminosity weighted.*

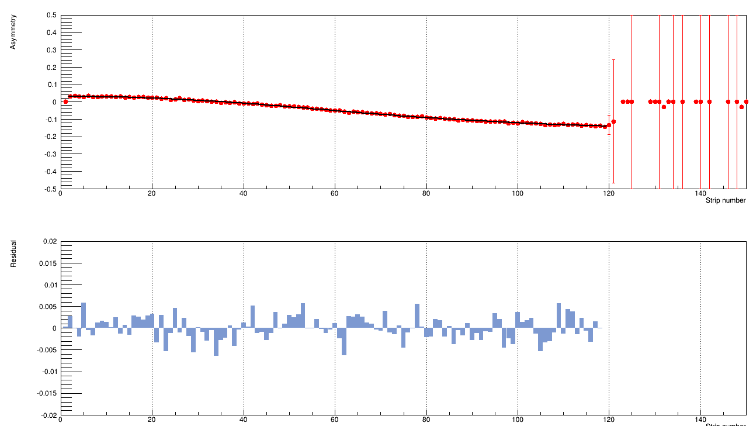

Figure 8: *Compton asymmetry in the electron detector for 85% polarization is shown. The asymmetry has been fit and includes residuals.*

	Polarization	Compton Edge	χ^2/NDF
No Window	84.90 $\pm$ 0.39	118.24 $\pm$ 0.18	1.74
Window	84.40 $\pm$ 0.40	118.36 $\pm$ 0.28	2.48

Table 1: *Fit results to Compton asymmetry with and without shielding window.*

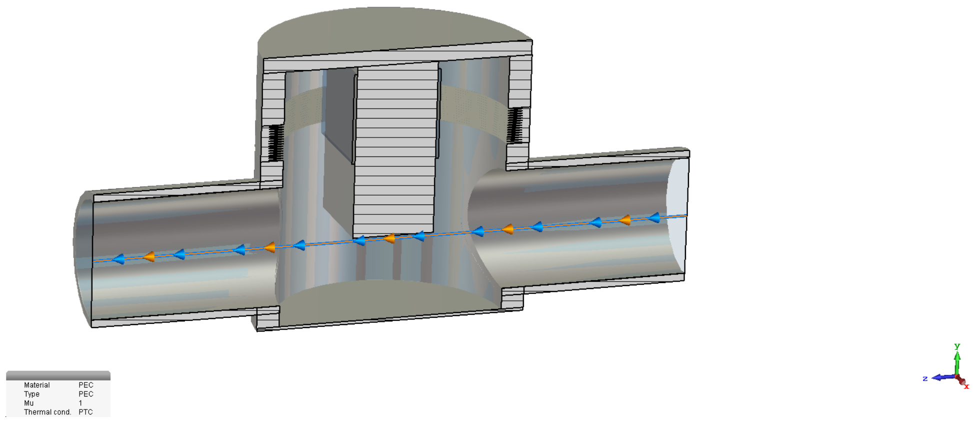

Figure 9: Roman Pot CST model by Nicola Minafra

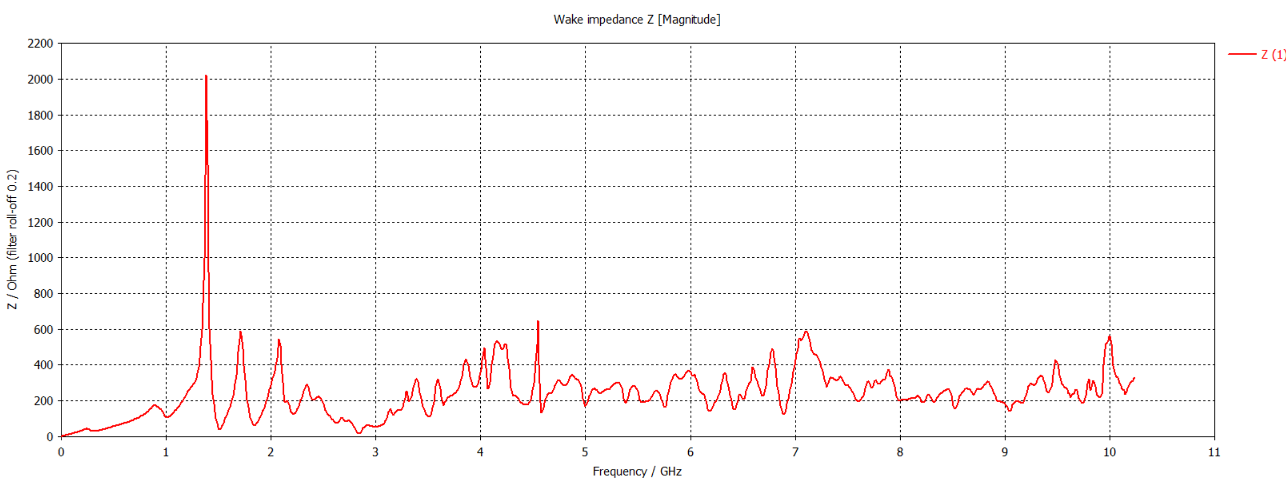

Figure 10: Impedance spectrum for JLEIC beam structure

Wakefield estimate With the help Nicola Minafra a more realistic modelization file as show in Fig. 9 of the Roman pot was produced based on the TOTEM Roman Pot design [2] to be fed in the simulation.

The computation of the impedance 1.1.3 looked much better with less divergent peaks (only one around 1.2 GHz). The following plot was produced after running the simulation for 10 days.

Power deposition in the Roman Pot was computed to be around 540 Watts for the lower energy setting Fig.11 at 0.75 A which would corresponds to 2160 W at the maximum current of 3A and 870 W for the high CM energy Fig.12 where the max current will be 0.75 A. The value is fairly high for the high current low energy kinematics but could be optimized and is in a manageable order of magnitude.

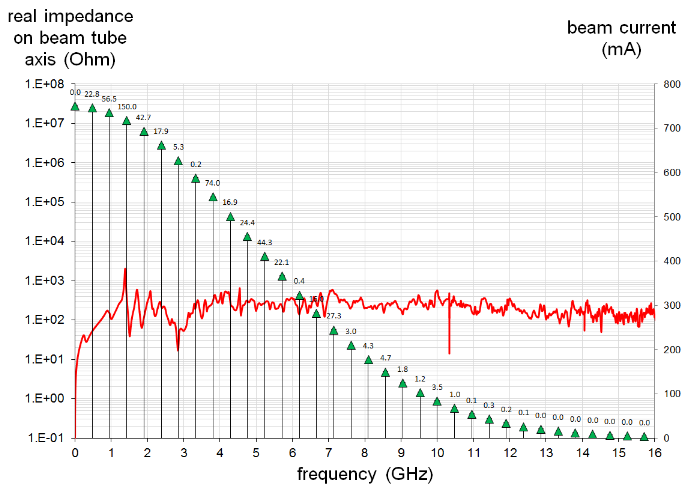

Figure 11: Beam profile for low and medium Center of Mass Energy at 476.3 MHz for current of 0.75 A

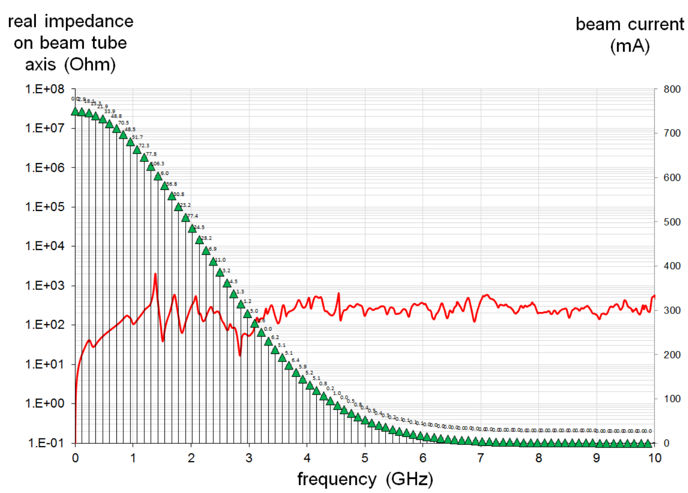

Figure 12: Beam profile for High Center of Mass Energy at 119 MHz for current of 0.75 A

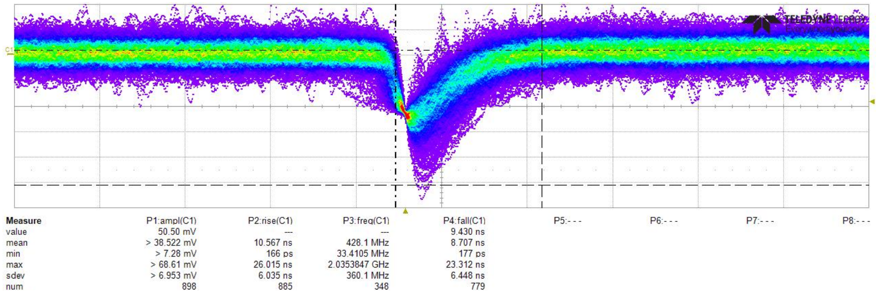

Figure 13: Persistence of diamond pulses with beta source at 200V bias voltage

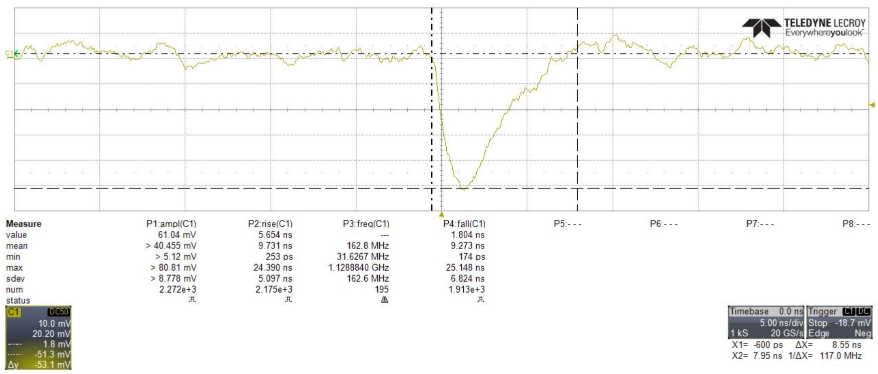

Figure 14: Width measurement of diamond pulse with Fast KU amplifier of diamond detector at 200 V

1.2 Result on feasibility for separating bunches for ERHIC

Typically speed of semiconductor detector is driven by the preamplifier and shaping electronics which is optimized to collect as much charge as possible for the best signal to noise ration often at cost of very long integration time. During our meeting with Nicola Minafra in Kansas University we took the opportunity to test their fast amplifier design. Signal with diamond and silicon detectors were recorded with a beta source and with a laser for the silicon detector. As expected detector response was much faster than 100 ns. For diamond detector, the pulse is around 8.55 ns wide as shown in Fig.14

For silicon detector, the pulse width was a bit larger around 14 ns. The signal is not as clean as for diamond, this still needs to be understood (we suspect a inhomogenous field due to only one strip being powered up but it would need to be tested by powering more than one strip). The silicon used was a 500 um thick silicon detector with 250 μm strips.

Since silicon is sensitive to the laser (unlike the diamond), we were able to test the timing response of the fast amplifier with the silicon diamond using a pulsed laser up to 10 MHz repetition rate, to make sure no overlap or saturation effect occurs because of a slow shaping time.

Both behaved very cleanly, the jitter is very small Fig 17 . The pulses are cleanly separated at 10 MHz Fig. 18, which leads us to the conclusion that using this kind of shaping amplifier electronics and any semi-conductor detector would be able to be fast enough for eRHIC ERL beam structure at 9.8 MHz. The main issue left to be addressed being radiation hardness of the detector and detector efficiency for minimum ionizing particles.

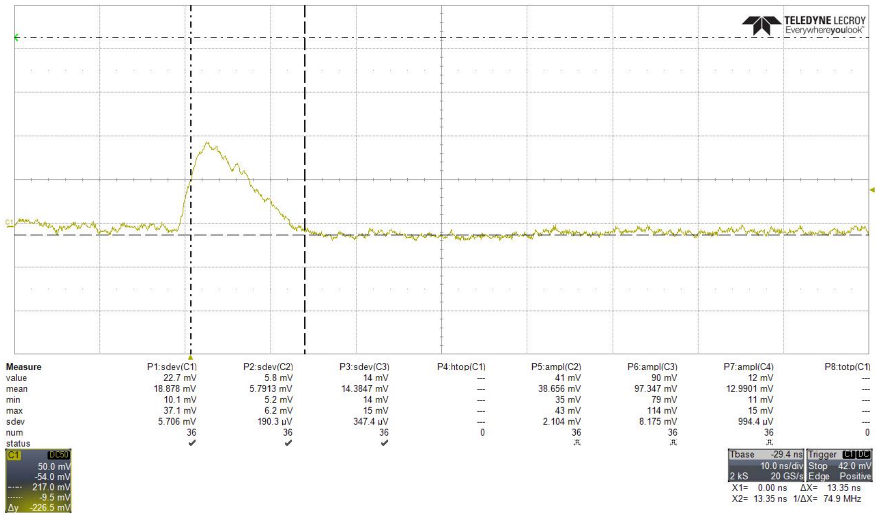

Figure 15: Single silicon detector pulse with beta source at 200V bias voltage

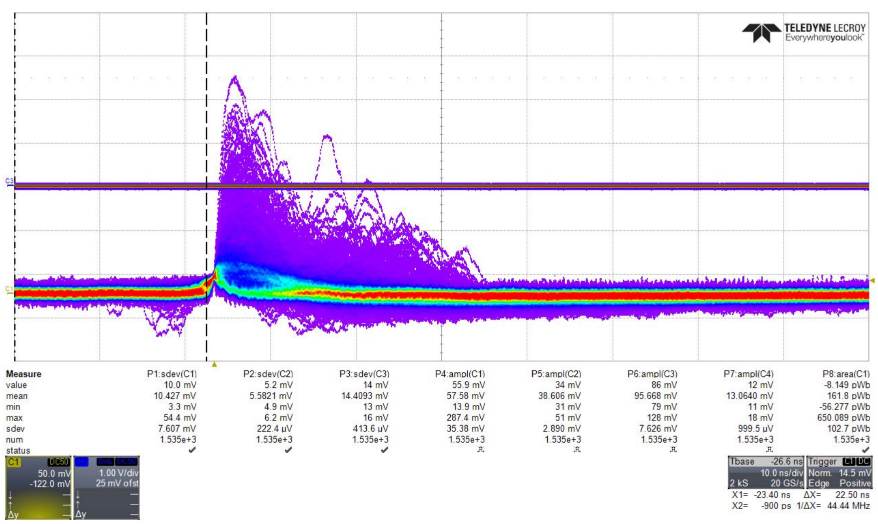

Figure 16: Persistence silicon detector pulse with beta source at 200V bias voltage

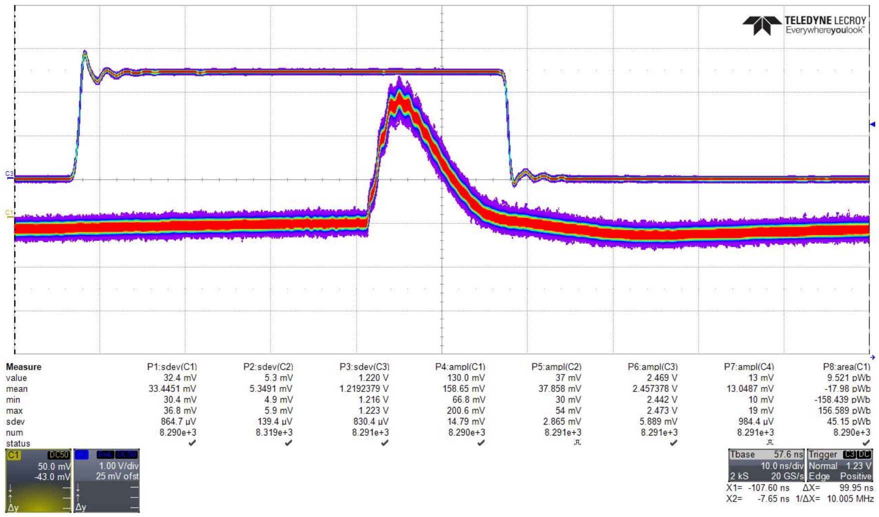

Figure 17: Pulse silicon at 10 MHz, large time scale

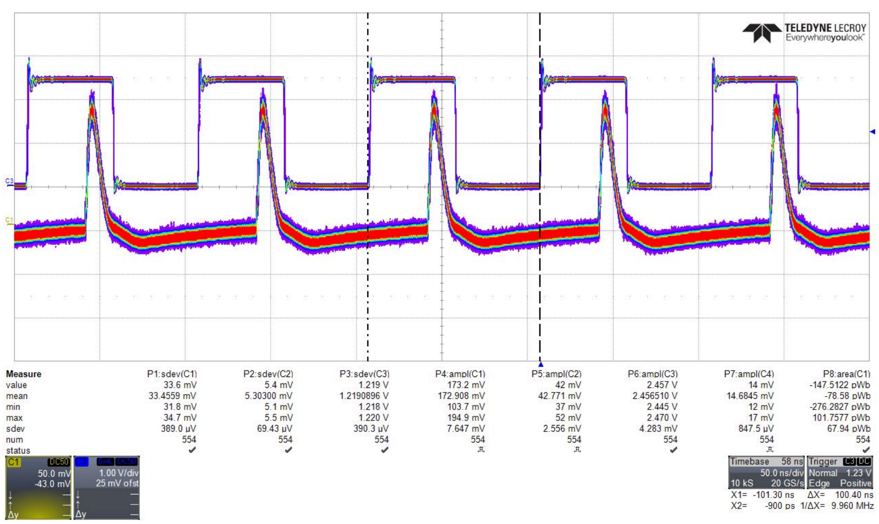

Figure 18: Pulse silicon at 10 MHz, large time scale

Personnel	% FTE	location	tasks
Alexandre Camsonne	20	JLab	General organization,Wakefield studies, postdoc supervision
David Gaskell	5	JLab	Geant3, Laser system, postdoc supervision
Joshua Hoskins	50	JLab	GEMC simulation and data analysis
Michael J. Murray	5	Kansas University	detector, electronics
Christophe Royon	5	Kansas University	detector, electronics
Nicola Minafra	5	Kansas University	Wakefield and amplifier test

Table 2: Manpower estimate for 2016-2017 period

1.3 Manpower for 2016-2017 period

Manpower summary for 2017.

1.4 Future

1.4.1 What is planned for the next funding cycle and beyond ? How, if at all, is this planning different from the original plan ?

This year funding is the wrapping up of the study of the electron Compton detector with simulation. With the Compton Generator and polarization software working, we can focus on systematic studies to optimize the detector performances and design.

- more realistic design of Roman Pot geometry in simulation (was simply a plate for now)
- optimize number of strips and strip size for best systematics with as few channels as possible
- optimization of wakefield shielding on measurement
- optimization of thin window for improved systematics
- determination of expected accuracy of the measurement
- determine the contribution of beam induced background using molflow and synrad package

In addition to those studies, one major source of background that has not been taken into account is the outgassing due to synchrotron radiation in the beam pipe. We will learn using the tools Molflow and Synrad to determine if this could be a major source of background. We will also work with KU group to optimize the impedance and make sure the HOM are well under control. The last month of work will be dedicated to a summary of the simulation result and detector text to be submitted to a peer-reviewed journal in addition to the full report. Documentation so that simulation and analysis software can be carried on and used by other groups.

1.4.2 What are the critical issues ?

The critical issues to be addresses by this proposal :

- determine all the possible background contribution to ensure a single pass laser give a sufficient signal to background ratio
- optmize the geometry and shielding to reduce the power deposited by the beam and check the design is still able to reach subpercent accuracy
- determine ultimate accuracy expected with a roman pot design and a detector in vacuum

1.5 Manpower

Planned manpower for 2017/2018 period.

In addition to the core manpower, Michael Sullivan from SLAC, Robert Rimmer and Haipeng Wang from JLab RF group are advising about Wakefield HOM modelling.

Personnel	% FTE	location	tasks
Alexandre Camsonne	20	JLab	General organization,Wakefield studies, postdoc supervision
David Gaskell	5	JLab	Geant3, Laser system, postdoc supervision
Joshua Hoskins	50	JLab	GEMC simulation and data analysis
Michael J. Murray	5	Kansas University	detector, electronics
Christophe Royon	5	Kansas University	detector, electronics
Nicola Minafra	15	Kansas University	Wakefield and amplifier design

Task	Time estimate
Analysis checks	1 month
Realistic Roman Pot Geometry	2 month
Wakefield	3 month
Beam induced background	2 months
Paper, documentation	1 months

Table 3: Rough timeline table

1.6 External funding

None

1.7 Publications

Plan for NIM publication next year

2 Proposal

2.1 Proposal deliverables

2.1.1 Software and simulation

This year proposal is planning to take advantage of the completed software to study systematics errors of the detector, optimize the geometry to improve the power deposited by the wakefield. The proposal deliverables are :

- implement realistic roman pot geometry and study systematics of the detector in particularly optimize strip size and number of channels
- optimize the size and number of channels since Fast Electronics number of channel is limited for now
- continue the work on wakefield to optimize the geometry, make sure the estimation are reliable and evaluate time and computer power needed for the impedance study of the Roman Pots for high repetition rate ring ring machine such as JLEIC or eRHIC ring ring
- have a preliminary result of beam induced background due to outgassing using the Molflow and Synrad
- write final final R&D report summarizing the complete study and submit a summarized version of the report to a peer reviewed journal
- document all the produce simulation and analysis software for future use by other groups

A rough timelime follow in Table 3

2.2 Wakefield Evaluation and Roman Pot Design

The main challenges presented by the EIC in the case of the ring-ring designs are due to the bunch structure: a bunch length of 300ps requires the optimization of the cavity up to several GHz, which means that the small details of the cavity cannot be neglected. Consequently, the optimization process requires the use of very fine mesh for the numerical simulation, i.e. large computing time. The geometry

Allocation	Amount (K$)	Amount with overhead (K$)	Cumulative (K$)
Postdoc	35	54.075	Simulation, analysis, documentation
Travel	15	23.175	
Nicola Minafra	12	18.54	Wakefield study
CST license	7	10.815	Wakefield study
Total	67 K$	103.52 K$	

Table 4: 2017 Budget request

Budget	Amount (K$)	
Full	103.52	All deliverables, optimized wakefield
-20%	82.8	Partial wakefield
-40%	62.1	No wakefield, limited travel

Table 5: 2017 Budget scenario

of the initial Roman Pots design will be optimized with the help of Nicola Minafra for 2 months for the JLEIC machine. We plan to get in touch with the BNL accelerator group since they might be interested to carry out the same studies for the eRHIC roman pots for the ring ring design. This work will be done in collaboration with the Kansas University group and the JLab SRF group.

3 Budget

- We request to continue funding for the postdoc to continue the detector studies using the developed software. Beam induced background background will be evaluated. Documentation of the software and final report will be produced. The base salary for 50 % is 35 K$ corresponding to 54.075K$ this constitute the minimal budget at roughly. He will be based at Jefferson Laboratory supervised by Alexandre Camsonne and David Gaskell.
- The travel budget stays the same allowing one international trip and to attend the EIC R&D meeting and EIC user group meeting and visit to JLAB and BNL. In case of need to be in the -40% scenario, travel money would be reduced to 6K$ preventing any international travel.
- two months of Nicola Minafra time are requested to work, work on the Wakefield optimization will be done remotely from CERN and at JLab, Kansas University. Alexandre Camsonne will work with him when in the US. Nicola is otherwise in close contact with Christophe Royon and Michael Murray. Our minimum budget request is 42 K$ which corresponds to 64.9 K$ with overhead.
- a 6 months of additional CST license is requested to be able to run the optimization simulations

All costs have to include the standard overhead of 54.5%, to summarize we are requesting a full budget of 103.15 K$.

	Simulation	Wakefield	Travel	Sum
University of Manitoba	54.075	0	0	54.075
Kansas University	0	18.54	0	18.54
Jefferson Laboratory	0	10.8	23.2	34
Sum	54.075	29.34	23.2	

Table 6: 2017 Budget Matrix

References

[1] Minafra, Nicola, Development of a timing detector for the TOTEM experiment at the, LHC CERN-THESIS-2016-016, http://cds.cern.ch/record/2139815?ln=en

[2] Minafra, Nicola (U. Bari (main) ; INFN, Bari) RF Characterization of the New TOTEM Roman Pot CERN-TOTEM-NOTE-2013-003 , http://cds.cern.ch/record/1557361

[3] Amrendra Narayan, Determination of electron beam polarization using electron detector in Compton polarimeter with less than 1% statistical and systematic uncertainty
https://misportal.jlab.org/ul/publications/downloadFile.cfm?pub_id=13934